REMARKS

Applicant has carefully reviewed and considered the Office Action mailed on September 26, 2000, and the references cited therewith.

Claims 1, 3, 9, 12, 13, 14, 17, 18, 19 and 22 and new claims 26-31 are added; as a result, claims 1-31 are now pending in this application. Claims 1 and 11 are amended solely to correct a typographical error (which caused the 112 rejection) and not in response to any art reference or obviousness rejection by the Examiner, deleting an extraneous "second" descriptor. Claims 3 and 12 are amended to independent form to include all limitations of their respective base and any intervening claim(s).

Objections to the Drawings

The drawings were objected to because at least reference numeral 1957 was not shown. Red-lined drawings and replacement sheets showing this and other corrections to the drawings Figs. 18A and 19A are attached hereto. No new matter has been added. Formal corrections will be made upon receipt of a Notice of Allowance.

The Examiner objected to the drawings as not showing certain features specified in the claims. Applicant respectfully traverses the objection. Applicant notes that examples of a **picker** are picker 2000 of Figure 10 and 20 (see page 9 line 13; page 41 line 13; and elsewhere), however the scope of "picker" should not be limited to these examples. Applicant has amended claim 13 to replace "slide clamp" with -- tray-transfer device --, as supported by an example (labeled 1800 and 1802) on page 68 and Figure 18. Applicant points to rotator 1960 and/or motor 1962 as examples of **means for limiting** of claim 14 (This is supported in the specification on page 67 lines 27 to page 68 line 2:

> "The rotator 1960 includes stops so that the trays will essentially be flipped through 180°. A rotator motor 1962 is used to drive the rotator. The rotator motor can also have stops or be a motor that works between 0° and 180°.")

Applicant points to Figures 19C though 19G and page 70 lines 8-11 as drawing support for **slider** (e.g., elements 1928 and 1929):

> "In one embodiment, jaw 1930 is then slid laterally using slider motor 1928 and screw 1929, with a holder or pusher 1931 holding the devices in position above tray 89 as jaw 1930 is moved out of

the way."

Thus, Applicant respectfully request that the objections to the drawings be withdrawn.

§112 Rejection of the Claims

Claims 1-25 were rejected under 35 USC § 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which Applicant regards as the invention. Applicant respectfully traverses the rejection as to the assertion of claims 3, 12, 17, 20 and 22 requiring "simultaneously" since although embodiments are described in which the jaws are rotated simultaneously, the invention does not require that the jaws be rotated simultaneously in all instances (see Figures 19C-19G, for just one example). Similarly, example embodiments are described in which the trays engage one another, but this is not required. Thus, these claims are definite and clear without this change, and cover embodiments whether or not the jaws are rotated simultaneously. Applicant has also added new claims 27-31 that further distinguish embodiments that rotate the jaws simultaneously. In view of the amendments, Applicant respectfully requests that the §112 rejection of the claims be withdrawn.

§103 Rejection of the Claims

Claims 1, 2 and 11 were rejected under 35 USC § 103(a) as being unpatentable over Applicant's allegedly admitted prior art as discussed on pages 2-5 of the specification. Applicant respectfully traverses the rejection. The Examiner bears the initial burden of factually supporting any *prima facie* conclusion of obviousness. To establish a *prima facie* case of obviousness, three basic criteria must be met. First, there must be some suggestion or motivation, either in the references themselves, or in the knowledge generally available to one of ordinary skill in the art, to modify the reference or to combine reference teachings. Second, there must be a reasonable expectation of success. Finally, the prior art reference (or references when combined) must teach or suggest all of the claim limitations. M.P.E.P. §2142.

Applicant respectfully submits that the Examiner had failed to meet his burden of providing a prima facie case of obviousness. Instead, a conclusory statement is provided in the Office Action that "Since the inverting operation is usually done by hand, the provision of a

mechanism to perform this function would have been obvious to a person having ordinary skill in the art seeking efficiency and reduced labor costs." Applicant respectfully requests that the Examiner provide a reference or showing that a person having ordinary skill in the art seeking efficiency and reduced labor costs would have been motivated to provide the combination of all of the limitations recited in claim 1 and 11, and would have had a reasonable expectation of success with such a combination. Thus, Applicant respectfully request that the rejections to these claims be withdrawn.

Allowable Subject Matter

Claims 3-10 and 12-25 were indicated to be allowable if rewritten to overcome the rejection(s) under 35 USC § 112 set forth in the Office Action. In view of the above-presented amendments, claims 3-10 and 12-25 are believed to be in condition for allowance.

Unconsidered Document

The Examiner has noted on his Office Action Summary that the Yang article referred to on Applicant's Form 1449 filed November 19, 1999 was unreadable. A legible copy is attached hereto, along with a new Form 1449. **Applicant respectfully requests that the Examiner review the Yang article and return the initialled Form 1449 with his next official communication.**

Conclusion

Applicant respectfully submits that the claims are in condition for allowance and notification to that effect is earnestly requested. The Examiner is invited to telephone Applicant's attorney (612-373-6949) to facilitate prosecution of this application.

If necessary, please charge any additional fees or credit overpayment to Deposit Account No. 19-0743.

Respectfully submitted,

ARYE MALEK ET AL.

By their Representatives,

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Date ______________________ By ______________________________
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CERTIFICATE UNDER 37 CFR 1.8: The undersigned hereby certifies that this correspondence is being deposited with the United States Postal Service with sufficient postage as first class mail, in an envelope addressed to: Commissioner of Patents, Washington, D.C. 20231, on this 26th day of January 2001.

Charles A. Lemaire
Name

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Signature

Volume 1

Proceedings

1986 IEEE INTERNATIONAL CONFERENCE ON

ROBOTICS AND AUTOMATION

IEEE Computer Society Order Number 695
Library of Congress Number 86-80341
IEEE Catalog Number 86CH2282-2
ISBN 0-8186-0695-9

April 7-10, 1986
The San Francisco Hilton and Tower
San Francisco, California

Sponsored by:
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Published by IEEE Computer Society Press
1730 Massachusetts Avenue, N.W.
Washington, D.C. 20036-1903

IEEE Computer Society Order Number 695
Library of Congress Number 86-80341
IEEE Catalog Number 86CH2282-2
ISBN 0-8186-0695-9 (paper)
ISBN 0-8186-4695-0 (microfiche)
ISBN 0-8186-8695-2 (case)

Order from: IEEE Computer Society
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DETERMINATION OF THE IDENTITY, POSITION AND ORIENTATION OF THE TOPMOST OBJECT IN A PILE: SOME FURTHER EXPERIMENTS

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ABSTRACT

In a recent report [7], we proposed algorithms for segmenting out the visible part of the topmost object from a pile of planar and curved objects. Planar objects considered were of convex polyhedral type, such as prisms, boxes, wedges, etc; and the curved objects were of the type that could be recognized uniquely by using the Extended Gaussian Image, such object-types being cylinders, cones, spheres, ellipsoids, toruses, etc. For input these algorithms used 3-D vision data acquired with a structured light scanner.

In this report, we will review some of the algorithms presented earlier and show our latest experimental results on scenes that are more complex than before. In our presentation at the conference, we also plan to show some manipulation experiments that for sensory feedback use 3-D vision data analyzed according to the algorithms presented here.

1. Introduction

Seemingly simple operations like picking up the topmost object from a pile of objects can be exceedingly difficult for a robot, even when the robot is endowed with sensory capabilities for the purpose of dealing with a random environment. For many years, it was hoped by the computer vision community that we would succeed in implementing on a computer the laws of Gestalt organization and stereo perception that allow us humans to perform such tasks so effortlessly. More recently, the attitude has been that while research must continue in simulating these human abilities, which appear to be guided by knowledge and driven by expectations, we must in the meantime also look for purely engineering solutions to the sensory feedback problems of robots.

During the past few years, many engineering solutions have been shown to be feasible. For example, if the aim is to simply pick objects from a bin and if the object surfaces are smooth it is possible to use a vacuum gripper [5]. If the aim is a bit more sophisticated, such as sorting a pile of objects on the basis of shape, one must now use the sensory data (in most cases, vision) to not only locate the least occluded object -- usually topmost -- but also recognize its shape in two or three dimensions; in addition, it may be necessary to compute optimum holdsites.

With vision sensing, because of difficulties with the segmentation and grouping of photometric information, it is now generally believed that when the objects involved are inherently 3-D in nature (as opposed to being flattish), one must resort to range maps for scene analysis. Of course, the ideal would be to use the human-like stereo vision capability for generating the range maps with two or more cameras; but, in practice, for reliable and sufficiently dense data, a more engineering solution must be used -- structured light.

In [7], we presented algorithms for analyzing structured light range maps for the visible part of the topmost object in a scene. Here, we will demonstrate more recent results on scenes that are more complex. We will also review the two algorithms: one for analyzing scenes consisting of planar objects and the other for analyzing scenes of curved objects; this we will do for the sake of completeness.

The reader is also referred to [7] for a simpler approach to determining the center coordinates of a tesselated Gaussian spheres on which the measured surface normals are mapped; the purpose being to construct orientation histograms for object recognition..

The problem of locating and identifying the topmost object in a pile is a specialized case of scene analysis with 3-D vision; much has been done in that area lately. Oshima and Shirai [6] have segmented scenes consisting of polyhedral and curved objects by using a region growing technique; the overall scene was then described in terms of properties of regions and relations between them. Horn and Ikeuchi [4] have used the Extended Gaussian Image to determine the identity, orientation of an object that is a part of a small pile. Bolles [1] has used structured light range data to quickly and reliably locate cylinders of a specified diameter in a pile of cylinders. We have described in [2] a procedure for pile analysis that correctly segments a structured light generated edge-vertex description of a scene consisting of convex polyhedral objects. Dessimoz et al. [3] have used

This work was supported by the National Science Foundation and Purdue ERC (Engineering Research Center for Intelligent Manufacturing).

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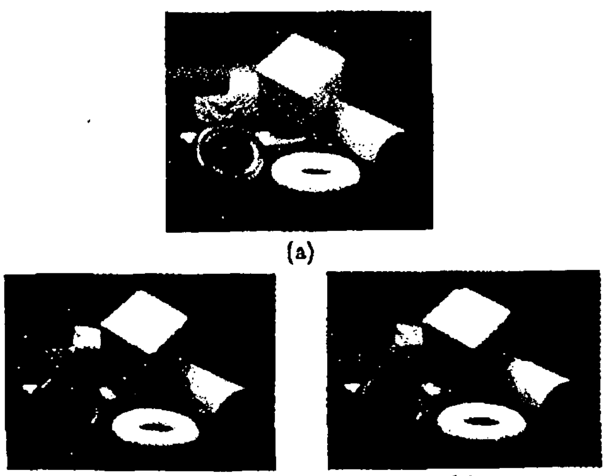
a matched filter type of implementation in which one first takes note of the geometry and the mechanics of how the end-effector would pick up an object; this consideration then leads to a set of features that can be invoked to identify the object if it is successfully grasped by the robot.

2. Testing the Topmost Visible Surface for Planarity

Before we can test the topmost surface for planarity, it must first be located. Fortunately, with 3-D vision data that is trivially accomplished by seeking out the pixel with the largest z-coordinate, which corresponds to the maximum height above the work table (Fig. 1b). (If there exist many pixels whose maximal heights are identical – this can happen if a straight edge of the topmost object is parallel to the work table – it is possible to choose any one of them as the topmost pixel.) An NxN set of pixels containing the topmost pixel is then defined as the topmost patch (Fig. 1c); and a 3x3 set of patches, containing the topmost patch at the center, is then tested for the planarity of the topmost surface. The size of the patches (NxN) is heuristically determined; if it is too small, the planarity test may not be reliable. We have used N=8.

The planarity test measures the variation in surface normals over this 3x3 set of patches; each surface normal being calculated by performing a least-mean-squares fit of a plane to the corresponding 8x8 cluster of pixels. To give greater credibility to the planarity test, we can also examine the the Gaussian and mean curvatures, since over regions that are declared to be planar both should be zero. (For further details on how we compute these two curvatures, the reader is referred to [8].)



(a) (b) (c)

Fig. 1: (a) Depicted here is a piled scene in which a cube is the topmost object. (b) Topmost point in this scene is a corner point of the cube. (c) Illustrated here is the topmost patch comprising 8x8 cluster of points where the topmost point is positioned at the center.

If with these tests it is determined that the surface region under examination is indeed planar, the object (or, at least its topmost surface) is declared planar; otherwise, it is assumed to be curved. In some cases it is possible that the 8x8 patch containing the topmost pixel might straddle an edge close by; clearly we do not wish such a patch to contribute to planarity decisions. These can be discarded from further consideration by putting a threshold on the error between the fitted plane and the pixel positions, as was done first in [6].

3. Segmentation of Visible Part of the Topmost Planar Object

If the topmost visible surface is declared planar by the preceding procedure, the rest of this surface is extracted by a region growing procedure utilizing the simple heuristics that all the surface normals of the patches on the topmost surface must point in essentially the same direction (Surface Normal Constraint) and that the patches be adjacent (Adjacency Constraint). A region is allowed to grow until either there is nothing more to merge, or until we have exceeded some specified distance from the starting patch; this distance reflecting our knowledge of the maximum expected size of the objects in the scene.

The process of merging can be made somewhat faster if at the beginning we also estimate the directions toward which most of the topmost surface lies from the vantage point of the starting patch. For example, if we knew that the starting patch was at the top right corner of the surface, then the growing process could be confined to the left of and below the starting patch. Determination of where the starting patch lies in relation to the rest of surface can in some cases be made by examining a neighborhood set of patches.

After the topmost surface is extracted, the rest of the visible portion of the topmost object must also be segmented out. In a sense, this is a continuation of the region growing process mentioned above, and a similar set of heuristics is now called for; the ones that we use are:

1. Adjacency Constraint: To act as a starting patch of an adjoint surface, a patch must be a neighbor of one of the patches of the extracted topmost surface.
2. Surface Normal Constraints: Patches on an adjoining surface must have the same surface normals as the starting patch for that surface. In some cases, based on the knowledge available about the objects in the scene, constraints may be imposed on the permissible angles for the patch surface normals on adjoining surfaces. For example, if the objects are known to be rectangular, we may not accept a patch as a seed for an adjoining surface unless its surface normal is perpendicular to the normal associated with the topmost surface.

3. Object Convexity Constraint: All surfaces that adjoin the topmost surface must also satisfy the convexity condition that says that those points that lie on a straight line connecting any location on the topmost surface and a point on an adjoining surface must all lie behind both surfaces when those points are viewed along the direction which is the inverse of the surface normal of either the topmost surface or the adjoining surface. As shown in Fig. 2, P_3, which is on a line connecting P_1 and P_2, is behind S_t when it is viewed along V_t, which is the inverse of the surface normal of the topmost surface; and behind S_a when it is viewed along the V_a.

Fig. 3a illustrates a light stripe image of the scene in Fig. 1a, and Fig. 3b shows the topmost planar object (a cube) segmented out by the region growing procedure.

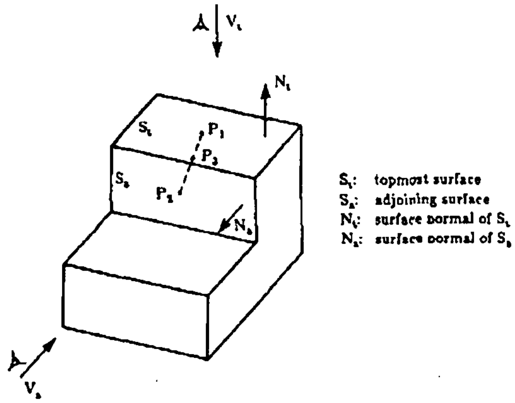


Fig. 2: Illustrated here is a concave polyhedral object in which topmost surface (S_t) and its adjoining surface (S_a) satisfy convexity constraint.

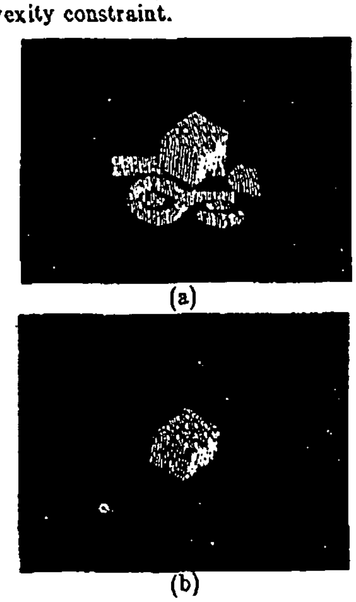


Fig. 3: (a) Depicted here is a light stripe image of the scene in Fig. 1. (b) Illustrated here is the visible part of a cube at the top of the pile.

4. Isolation of the Topmost Curved Object

Region growing is not the best strategy for extracting the visible portion of a topmost curved object; the difficulty being caused by variations in the surface normals over such surfaces.

A better strategy for curved objects is to locate the outer boundary of the topmost curved surface by finding the defining range discontinuities. This is accomplished in the following manner. From the topmost point, we sequentially proceed outwards in eight directions, E, W, N, S, NE, NW, SE, and SW, until along each direction we reach a point of a significant range discontinuity (Fig. 4); this pursuit being abandoned if a discontinuity is not found within a certain distance, which depends upon our a priori knowledge of the maximum dimension of the objects in the scene. After the range discontinuity points are detected in the eight or fewer directions, we select one of those as a starting point for outer boundary tracking. The rest are designated as "posts" on which the extracted outer boundary must "hang". Suppose, after tracking out from the starting point for a certain predetermined distance, a post is not encountered, we abandon that track, and select one of the other posts as a starting point. Tracking proceeds from post to post. After one complete attempt at going around all the posts in one direction, we go back to those post pairs where tracking proved unsuccessful; for these the tracking is then attempted in the opposite direction. If that also fails, we either connect the two posts by a straight line; or if greater precision is demanded, we might set up another post between the offending pair and retry the procedure.

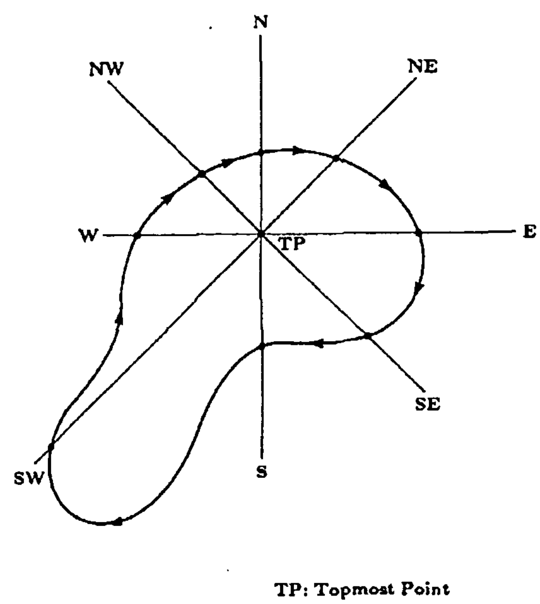


Fig. 4: (a) Described here is the outer boundary of the topmost curved object and its posts in eight cardinal directions from the topmost point.

However, for an object like a torus, whose range map from many viewpoints would contain a hole inside the outer boundary, some posts may not reside on the outer boundary at all. As shown in Fig. 5, for the viewpoint shown there, post 5 is located on the inner boundary of a torus, therefore the tracking process from post 4 to post 5, and from post 5 to post 6, will fail even if we subdivide the sectors between post pairs. As a result, we could lose almost half of the topmost object surface if we simply connected posts 4 and 6. To overcome this flaw, whenever there exist post pairs where tracking fails, one must meticulously examine regions around those posts to find out if there really exists a hole there, implying a torus like object.

This examination can be carried out by checking the polarity of the Gaussian curvature of the points around those posts. (Negative Gaussian curvature indicates that the region around the point is locally saddle shaped.) If the existence of a hole around a post is verified, we must then try to locate the third range discontinuity along that direction (P_b in Fig. 5) and use it as a new post for the purpose of further tracking.

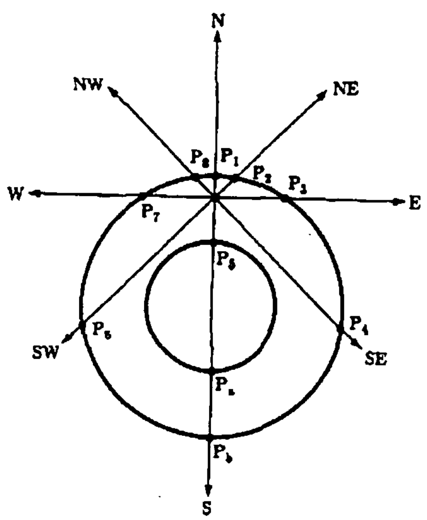


Fig. 5: An example where the first range discontinuity to the south (P_5) from the topmost point on a torus does not reside on the outer boundary of the torus; if points around P_5 have negative Gaussian curvature, the third range discontinuity (P_b) to the south is supposed to be on the outer boundary of the torus. Tracking around P_b is then retried.

After outer boundary of the topmost curved object is extracted, we are faced with the not so simple task of extracting the interior points.

This is accomplished by first extracting a minimum bounding rectangle containing the outer boundary points; this operation being trivial, but it does reduce the amount of data for further processing. To extract from this rectangle those points that are within the object boundary, we have devised a procedure which uses the polygon filling technique of computer graphics

The procedure is based on the principle that when a straight line intersects a closed boundary at, say, P1, P2, P3 .....,and Pn, all the points that lie on a chord between P1 and P2 must belong to the interior of the boundary; those that are on a chord joining P2 and P3 must be exterior to the boundary; those that are on a chord joining P3 and P4 must again be interior to the boundary; and so on (Fig. 6). The implication here is that if we can find all the horizontal scan lines that are simultaneously in the data frame and the extracted boundary of the topmost object, it should be a simple matter to fill out the interior.

The determination of the intersections of scan lines with the boundary is aided by the fact that the computer representation of the boundary is that of a polygon. The points of intersection of a scan line with each side of the polygon can be found by the following simple routine.

Let (I_1,J_1), and (I_2,J_2) be the two vertices of a particular side of the polygon. We then calculate

$$r = \frac{I_{scan} - I_1}{I_2 - I_1}$$

If $r < 0.0$ or $r > 1.0$, then the scan line does not touch the line segment; if $r = 0.0$ or 1.0, then the scanline intersects the start or ending vertices of the line segment, respectively. On the other hand, if $0.0 < r < 1.0$, then the scanline intersects the interior of the line segment and the coordinates of the intersection point are given by

$$I_i = I_{scan}$$

$$J_i = J_1 + r * (J_2 - J_1)$$

For each scanline, the intersection points with all sides of the polygon are collected, sorted from left to right in the order of increasing horizontal coordinate; and then the points between each pair are considered as the interior points of object region provided, of course, the range data is available at such points.

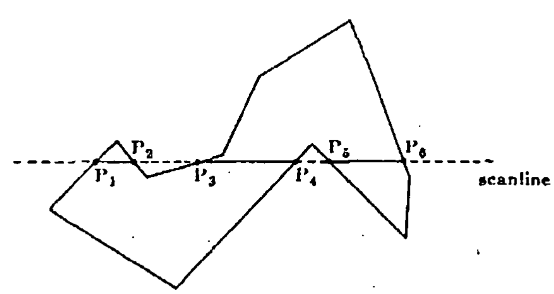


Fig. 6: Illustrated here are the intersection points of a scan line with the object boundary approximated by a polygon. Points that lie on the chords between the P_1 and P_2, P_3 and P_4, P_5 and P_6 belong to the interior of the boundary.

Fig. 7a illustrates a scene in which a cylinder is located at the top of the pile; Fig. 7b depicts a light stripe image of Fig. 7a; Fig. 7c shows the outer boundary of the cylinder; and Fig. 7d shows the visible part of the topmost object.

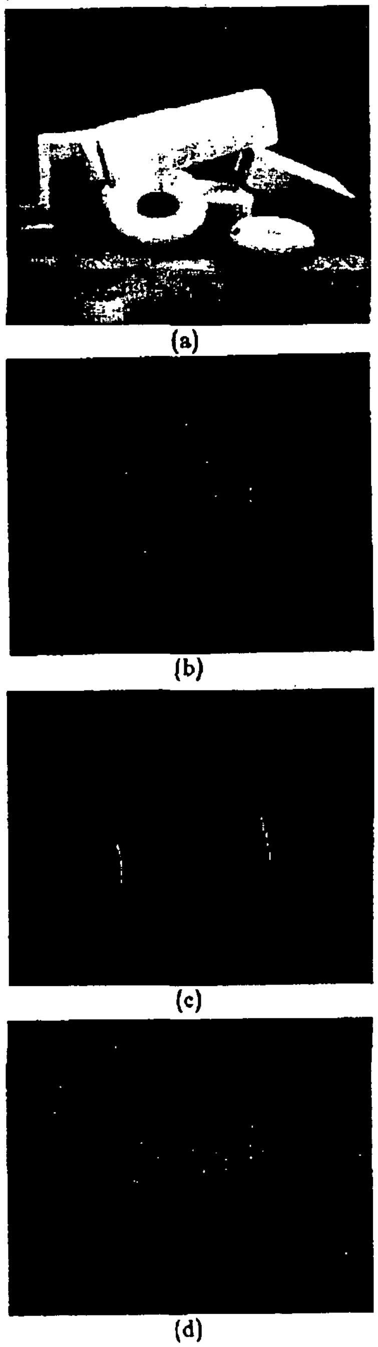


Fig. 7: (a) Illustrated is a piled scene in which a cylinder is located at the top of the heap. (b) Light stripe image of this scene. (c) Depicted here is the outer boundary of the cylinder. (d) Shown here is the visible part of the topmost object.

5. Representation and Recognition of th Topmost Object

For curved objects, after extracting the visible part we compute the local surface normals and surface curvatures (the mean and the Gaussian curvatures) by the technique discussed in [8]; whereas for planar objects only the local surface normals are computed. Surface normals are then mapped onto a Gaussian sphere to construct a orientation histogram. In [7], we have presented what appears to be a particularly simple approach to the calculation of the center coordinates of a Gaussian sphere.

When the topmost object is planar, its identity and attitude are subsequently determined by matching the observed EGI with prototype EGI's stored in the memory. For curved objects, in many cases the surface curvature information often provides direct clues as to the identity of the object; and in others, it definitely constrains the object type involved.

For instance, if the visible portion of the topmost curved object simultaneously contains points with negative, zero and positive Gaussian curvatures, it can be identified as a torus; in that case, the attitude of the torus can be determined by calculating the local surface orientations of those points that are characterized by zero Gaussian curvature. Cylindrical, conical and elliptic surfaces can also be discriminated by examining the polarities of Gaussian and mean curvatures and their distributions. Although both cylindrical and conical surfaces have zero Gaussian curvature and negative mean curvature, a cylindrical surface can be differentiated from a conical surface since the mean curvatures of the points on the cylindrical surface are all identical, while those on the conical surface are not. Once the identity of the topmost curved object is determined using the surface curvature information, its attitude is then determined by matching its observed EGI with its prototype. For further details about determining the identity and attitude of the topmost curved object, the reader is referred to [8].

At the conference, we plan to show manipulation experiments that demonstrate a robot first examining a scene with a 3-D vision sensor; calculating the identity, orientation and optimum gripping point of the topmost object in the pile; and then using this information to move the topmost object to a sorted pile consisting of similar objects.

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